

# Health Effects in a Casual Sample of Immigrants to Israel from Areas Contaminated by the Chernobyl Explosion

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We analyzed questionnaire and physician examination data for 1560 new immigrants from the former USSR divided into three groups by potential exposure to Chernobyl radiation. Two groups were chosen according to soil contamination by cesium-137 at former residences, as confirmed by our findings in a <sup>137</sup>Cs body burden study. The third group consisted of "liquidators," persons who worked at the Chernobyl site after the disaster. Liquidators had greater self-reported incidences of symptoms commonly accepted as acute effects of radiation exposure, increases in prevalence of hypertension, and more health complaints. Excesses of bronchial asthma and health complaints were reported in children from the more exposed communities. Asthma prevalence in children potentially exposed *in utero* appears to be increased eightfold. Older adults from more exposed areas had more hypertension as assessed by history and measurements. These findings suggest the possible association of radiation exposure with several nonmalignant effects. **Key words:** bronchial asthma epidemiology, cesium-137 soil contamination, Chernobyl fallout, environmental radioactivity, hypertension epidemiology, internal radiation exposure, ionizing radiation, noncancer radiation effects, occupational radiation exposures. *Environ Health Perspect* 103:936-941 (1995)

Health effects in connection with the Chernobyl explosion, which occurred 26 April 1986, are of widespread concern in Israel because about 100,000 people immigrated into the country from possibly contaminated zones between 1990 and 1993. Nonmalignant health disorders associated with Chernobyl exposure have been reported in populations from many regions of Byelorussia, Ukraine, and Russia. Health problems are especially prominent among people who were deliberately exposed due to their involvement in cleanup work after the disaster (1-3). These clean-up workers are called "liquidators" because they participated in liquidating the sequelae of the Chernobyl nuclear power station disaster.

A major problem in the study of such environmental contamination is that valid and reliable measurements of exposure are not generally available (4). Most of our subjects had undergone measurements of the body burden of cesium-137, using a portable, whole-body counter, in the autumn of 1991 provided to us by the Canadian Department of Health and Welfare. This same isotope (<sup>137</sup>Cs) was the basis for mapping ground-level contamination by the International Atomic Energy Agency (IAEA) (5) and Russian authorities. This map allowed us to classify the probable exposure of individuals according to the places they lived after the disaster, which is usually the place from which they emigrated.

We thus defined two groups with different exposures to long-term Chernobyl radia-

tion to determine if certain health effects differed between these groups. A third group, liquidators or salvage personnel, was presumed to be deliberately exposed to radiation in connection with their work assignments, and thus were subject to higher external and internal exposure, albeit to different isotopes and over different time periods, than the other two groups.

## Methods

The study sample consisted of 1560 immigrants (885 adults, 675 children and adolescents to age 18 years) who arrived in Israel during 1990-1991.

**Sample selection.** In spring of 1991, a group of faculty members from Ben Gurion University, Faculty of Health Sciences, recognizing the unusual problems facing some of these immigrants, established a clinic for counseling and evaluation. Individuals and families came to the "Chernobyl Clinic," based at Soroka Medical Center, on a voluntary basis. In autumn 1991, a portable, whole-body counter for measuring <sup>137</sup>Cs was made available by the Canadian Department of Health and Welfare. We then invited (by radio and newspapers) recent immigrants concerned about their health in connection with possible exposure to Chernobyl radiation to come in for a health evaluation. In a 5-week period, 1244 people underwent <sup>137</sup>Cs body burden measurements, interviews, and physical examinations. In subsequent months, a further 316 immigrants were questioned and examined. In review-

ing our initial findings, we were impressed by the frequency of thyroid enlargement, which we had not initially planned to evaluate. So, during the summer of 1992, we standardized our thyroid examination procedures and evaluated thyroid function and autoantibodies. We invited for reexamination all of the children seen in autumn 1991, and 180 of them returned, along with 129 additional children and their parents. These participants, along with the people who attended the Chernobyl Clinic seeking evaluation and counseling, accounted for 316 additional immigrants who were included in the total 1560 people in the study.

**Questionnaires.** Questionnaires (available on request from E. Kordysh) were administered after pretesting to obtain demographic data, exposure history, medical history, health status, smoking and dietary history, and, for children, history of birth and development.

**Gradients in assumed dose.** We designated communities in areas with <sup>137</sup>Cs soil contamination at the level <37 GBq/km<sup>2</sup> as "less exposed" and those with >37 GBq/km<sup>2</sup> as "more exposed," based on map data obtained by IAEA (5). This designation has been confirmed by our findings in the <sup>137</sup>Cs body burden study (6), as shown in Figure 1.

The population sample was stratified into 3 distinct groups by potential exposure: 1) liquidators (47 men and 8 women), persons who worked on ameliorating the consequences of the Chernobyl explosion, 2) 291 males and 397 females who had lived in more exposed areas, and 3) 351 males and

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466 females who had lived in the less exposed areas. The latter two groups are collectively referred to as "residents." The more exposed areas in Figure 1 include Gomel, Chernobyl, Mogilev, Mozyr, Korosten, Kalinkovichi, Narovlja, Klintzy, and Rechitza. All other areas, including Kiev, are classified as less exposed.

The group of liquidators is not homogeneous by kind of job (it includes deactivators, building workers, drivers, medical and sanitary personnel, and service workers), nor by the period and duration of work (work was performed from the first days after the fire and later, and for less or more than 1 month). The maximal accumulated dose reported is 25 rem. For most people, dose information is not reliable; for many it is missing. It is reasonable to assume a greater exposure in the first few weeks after the disaster than in a later period. We recognize the relevance for an exposure index of measured dose, calendar time of first employment, duration of employment, type and location of work, documented change in white or red cell counts, use of protective equipment, and occurrence of symptoms possibly related to radiation exposures. Such information is potentially available in records of these salvage workers; we also used a questionnaire to compile such data and are currently evaluating these data.

**Possible effects of radiation exposure.** We analyzed data reported for generally recognized symptoms of acute radiation sickness—nose bleeds, nausea, hair loss, diarrhea, bleeding into skin, blood in urine and stool, and drop in white blood cell count—which took place in residents in the first 2 months after the fire and in liquidators subsequent to the time of work. We analyzed physician-diagnosed as well as self-reported chronic health impairments. Diseases and symptoms were tabulated according to the *Classification of Health Problems in Primary Care* (7), used by Kupat Holim, the health care organization to which many of the subjects were referred.

**Physical examination.** Physicians measured pulse rate and arterial blood pressure (seated position) as well as weight and height of each subject. Consistent reporting of these measurements was restricted to the sample studied in the autumn 1991. The staff available during the body burden study allowed the use of the same physicians for examinations, who were blind to the exposure history. This practice could not be replicated for subjects seen later. These measurements were done blind as to former residence of the subjects. We examined thyroid and lymphatic glands of all the subjects by palpation.

### Statistical treatment of the data.

Statistical analysis was performed using EPINFO (USD, Inc., Stone Mountain, Georgia) and SPSS (McGraw Hill, Chicago, Illinois) programs. The ages were stratified into nine groups: 0–5, 6–9, 10–14, 15–18, 19–28, 29–38, 39–48, 49–58, and 59+ years.

For symptoms associated with acute exposure, distributions corresponded to age in 1986; for other health indices, distributions corresponded to age in 1991. We evaluated data by chi-square tests with Yates correction and, where small numbers were expected, with the Fisher's exact test. For age-stratified data, the Mantel-Haenszel test was used. The Student's *t*-test was used to evaluate the means of systolic and diastolic blood pressure. Adjustments for smoking, weight, and age were made for blood pressure data in adults, as well as for height and body mass in children. Sample distribution by age, sex, and possible exposure is presented in Table 1.

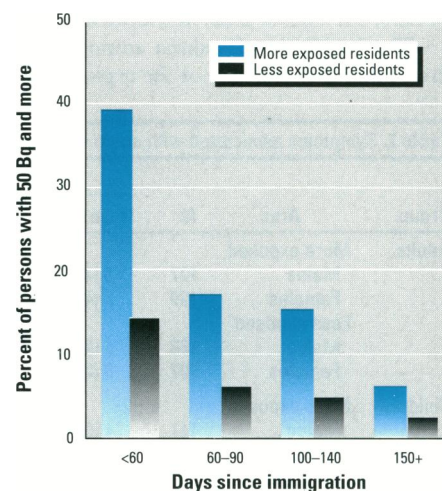
We consider probabilities less than 0.05 statistically significant. For a hypothesis-generating study such as this, statistical tests are useful for pointing to testable, specific hypotheses. Because this was not a hypothesis-testing study, we disregarded the multiplicity of statistical tests.

## Results

Of the 55 liquidators, 25 (45.5%) reported one or more symptoms associated with acute radiation exposure. The frequency of these symptoms was 22.4% among former adult residents compared with liquidators, ( $p < 0.003$ ) and 18.8% among children. All symptoms were reported more often by liquidators, but a statistically significant excess

was found only for nausea and decreased white blood cell count. Information on white cell count was available for 81.8% of liquidators and 79.6% of residents. Significant differences in reported frequency of hair loss in males was found for liquidators aged 29–38 years (29.4% versus 5.8% for residents;  $p < 0.02$ ).

In female children from the more exposed zones, nose bleeds were significantly more frequent than among female children from the less exposed area (15.7% compared to 7.6%). Among adults males from the more exposed communities, nausea was reported twice as frequently than among the males from less exposed areas, but the difference did not reach conventional levels of significance (Table 2).



**Figure 1.** Percent of radiocesium tests with 50 Bq and more by days since immigration and former residence.  $p < 0.05$  for each time-period difference. Reproduced with permission (6).

**Table 1.** Distribution of subjects by age, gender, and possible exposure, examined in 1991–1992

Age		More exposed		Less exposed		Liquidators	
		Male	Female	Male	Female	Male	Female
0–5	Total <sup>a</sup>	42	39	41	38		
	Initial	27	27	31	25		
6–9	Total	41	44	48	48		
	Initial	31	33	30	38		
10–14	Total	69	66	64	37		
	Initial	54	66	44	22		
15–18	Total	22	33	20	23		
	Initial	19	23	15	15		
19–28	Total	18	26	24	46	9	2
	Initial	14	22	18	40	7	2
29–38	Total	31	85	57	104	16	3
	Initial	23	72	45	77	13	2
39–48	Total	28	34	38	69	16	1
	Initial	24	27	30	55	14	1
49–58	Total	15	25	24	38	5	0
	Initial	12	21	23	32	4	
59+	Total	25	45	35	63	1	2
	Initial	19	41	33	56	1	2
All	Total	291	397	351	466	47	8
	Initial	223	332	269	360	39	7

<sup>a</sup>Total, 1991–1992; initial, 1991.

Among 0- to 14-year-old boys and girls from more exposed areas, rates of asthma were 5.4% and 3.4%, respectively, which is 2.8 and 2.1 times higher than the rates for those from less exposed communities (1.9% for boys and 1.6% for girls; Fig. 2).

In adults, onset of asthma was only reported prior to 1986, and no difference by exposure was found (Fig. 2).

For children who were *in utero* at time of the Chernobyl accident, cumulative asthma incidence reached 20% (5/25) by 1991, which is about eightfold higher than in all the other children (average of 2.4%,  $p < 0.001$ ; Fig. 3). Twelve children from Gomel and six from Kiev were potentially exposed *in utero*. Seven children from other less exposed communities were possibly exposed *in utero*, but none of them developed asthma.

The incidence of asthma among children *in utero* at the time of the explosion is

sevenfold and fourfold higher than among children one year older (2.9%,  $p < 0.05$ ) or one year younger (5.6%), respectively. Of the five children who were *in utero* at the time of the explosion and who developed asthma in the first five years of life, three were from Gomel, in the more exposed area, and two were from Kiev, in the less exposed area. Recontact with the mothers of these children confirmed that the asthma was persistent and that the children were under clinical treatment for asthma.

In liquidators older than 38 years, the prevalence of physician-diagnosed hypertension was greater than among residents. For liquidators aged 38–48, the rates were 35.3% versus 27.1% in residents; for those aged 49–58, the rates were 60% versus 38.6%; and among those 59 and over, the rates were 66.6% versus 47.8% among residents.

There was a nonsignificant excess of

hypertension in the 49- to 58-year-old former residents of more exposed areas (37.2% versus 29.0% in less exposed areas).

A significant relationship between occurrence of symptoms associated with acute radiation exposure and development of hypertension was found among liquidators; 28% who reported such symptoms had hypertension, in contrast to 7.1% who did not report such symptoms.

For the 19 males 59 years old and over from the more exposed areas, the measured blood pressure was significantly greater than for the 33 males from the less exposed areas (153.7/93.4 versus 140.6/86.6). A history of hypertension was paralleled by increased systolic pressure for men aged 49–58: 138.8 for liquidators ( $N = 4$ , (SD 19.6) versus 132.1 for residents ( $N = 34$ , SD 11.8).

Rates of goiter prevalence before the Chernobyl disaster were almost equal among residents from more exposed areas (15.1%) and residents from less exposed areas (14.4%). The areas being compared were thought to differ in  $^{137}\text{Cs}$  pollution, but may not have differed in exposures to external radiation or to radio-iodine.

Thyroid palpation in 309 children (156 from the more exposed area and 153 from the less exposed), performed by experienced physicians, also did not reveal differences in findings of enlargement of the thyroid gland between groups by former residence (Fig. 4).

The prevalences of nodules were 7.7% and 5.9% for children from more exposed and less exposed areas, respectively (Fig. 4). There was a marked contrast between nodules in people from Gomel (6.9%) and Kiev (2.9%). For other communities in the more exposed category, this figure was 9.1%, versus 6.2% in other less exposed communities.

Differences between groups in frequency of other health conditions, assessed both

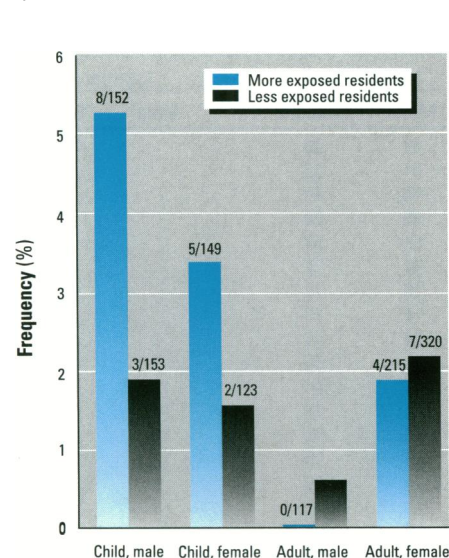
**Table 2.** Symptoms associated with acute exposure, 1991–1992<sup>a</sup>

Group	Area	N	Frequency of symptom (%)				
			Nose bleed	Hair loss	Nausea	Diarrhea	Bleeding into skin <sup>b</sup>
Adults	More exposed						
	Males	107	5 (4.7)	7 (6.5)	16 (15.0)	4 (3.7)	2 (1.9)
	Females	199	8 (4.0)	19 (9.5)	21 (10.6)	5 (2.5)	3 (1.5)
	Less exposed						
	Males	163	5 (3.1)	10 (6.1)	14 (8.6)	5 (3.1)	2 (1.2)
Children	Females	307	8 (2.6)	28 (9.1)	32 (10.4)	11 (3.6)	5 (1.6)
	More exposed						
	Males	141	14 (9.9)	3 (2.0)	16 (11.3)	6 (4.2)	2 (1.4)
	Females	172	27* (15.7)	7 (4.1)	19 (11.0)	8 (4.6)	4 (2.3)
	Less exposed						
	Males	132	13 (9.2)	1 (0.8)	18 (13.6)	9 (6.8)	2 (1.5)
	Females	145	11* (7.6)	7 (4.8)	18 (12.4)	6 (4.1)	2 (1.4)

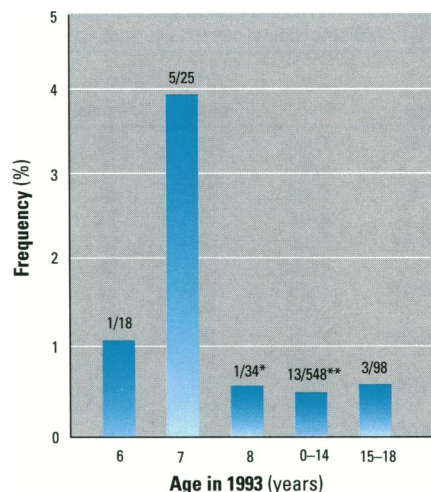
<sup>a</sup> Ages are as of 1986. Adults are persons  $\geq 19$  years old; children are  $\leq 18$  years old.

<sup>b</sup> Bleeding into skin includes bleeding into urine and feces.

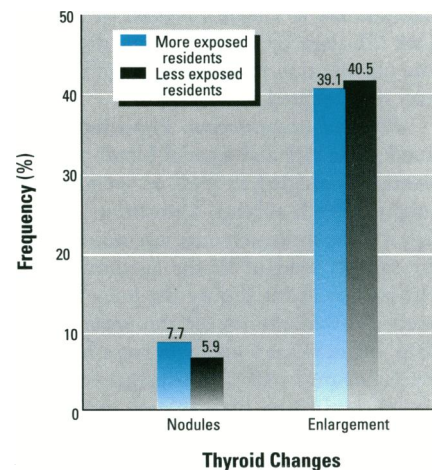
\* $p < 0.05$ .



**Figure 2.** Bronchial asthma prevalence by sex and former residence. Number of cases/sample size above bars.



**Figure 3.** Bronchial asthma prevalence in children and adolescents. Children 7 years old were *in utero* in April 1986, when the explosion occurred; children 0-14 include all others. Number of cases/sample size above bars; \* $p < 0.05$ ; \*\* $p < 0.001$  compared to children *in utero* in April 1986.



**Figure 4.** Thyroid changes in children by former residence.



by complaints and by physician diagnosis, are shown in Table 3. Liquidators demonstrated significantly higher rates for central nervous system (neurosis, sleep disorders, headache, dizziness), respiratory tract, and cardiovascular system disorders, as well as an increased tendency toward all other symptoms compared to former residents. A similar trend of increased health complaints was found for boys and girls who were born subsequent to the Chernobyl explosion and then lived in more exposed towns as compared to those from less exposed areas. Adolescents from more exposed areas also had more health complaints compared to those from other areas, with significant differences for cardiovascular system complaints.

## Discussion

### Sampling and Bias

The subjects of our study were not drawn from random population samples selected from an immigrant pool, but rather from Jewish immigrant volunteers concerned about their health due to their exposure to Chernobyl radiation; therefore, the possibility of selection bias is real. The subjects we examined came from many parts of Israel for evaluation, so we were able to make the observations we report here. We were able to offer reassurance as to lack of long-term effects from the body burden data and refer subjects for health care when necessary, whether or not their Chernobyl exposures were relevant.

Virtually every family believed that they had been exposed, and in our discussion of possible exposures we confirmed this. Our construction and validation of the two groups of more exposed and less exposed could not have led to a biased participation or response, however, because the classification was not established until after the subjects had been questioned and examined.

For these reasons we do not believe that there could have been an important contribution of selection, response, or observer bias to the differences between the more exposed and less exposed groups. On the other hand, our data cannot be extrapolated to other populations. While we cannot prove that the two different communities do not differ in some other ways, this problem is common in epidemiological analysis. Initial differences associated with presumed exposure differences are conventionally attributed to exposure until a better model or explanation is found. Nevertheless, associations with exposures in this population do increase the *a priori* probability of similar associations in other exposed populations.

Our data on hypertension from the less exposed community do not show significant differences from the general population of the former USSR (8). Elderly males from the more exposed areas had higher blood pressure than males of the same ages in Moscow and St. Petersburg (4).

Liquidators reported significantly more nausea and decreases in white blood cell counts than in residents; men aged 29–38 from more exposed areas had more hair loss and girls had more nose bleeds. We cannot exclude reporting bias for these findings. Although the interviewers and examiners were usually “blind” as to the exposure class of residents, they were not blind to the status of liquidators.

We could validate the decreases in white or red cell counts if we had access to complete records. Some of the liquidators brought complete health records and those who had a history of decreases in cell counts usually could tell us the actual counts and dates.

Other symptoms of radiation exposure must be considered with caution because of their nonspecificity, latency, and the consequent risk of recall bias. A group who volun-

teered for study because of health concerns might be more likely to recall symptoms than would a less health-conscious group.

The frequency of symptoms associated with acute radiation sickness was higher than expected. Stather and coauthors (9) reviewed dose–response information for acute radiation effects based on data from Hiroshima and Nagasaki and cancer therapy. For brief exposures to low-energy radiation (low LET) for <1 day, the ED<sub>50</sub> exposures for anorexia, nausea, fatigue, vomiting, and diarrhea are 0.97, 1.4, 1.5, 1.8, and 2.3 Gy, respectively. A threshold for vomiting of 0.5 Gy, is given. These relationships are for exposures to thorax, abdomen, and head and are thought to involve the autonomic nervous system. Skin exposures would be relevant to hair loss and bone marrow exposures to changes in white blood count and possibly to nose bleeds.

### Childhood Asthma and Exposure

Asthma is reported significantly more frequently in children who lived in more exposed areas. What we did not expect to find was that of the 25 children who were *in utero* at the time of the fire and explosion, 5 (20%) developed asthma during the first 5 years of life. This was not due to possible exposure only in the first trimester, when sensitivity of the fetus to external X-ray exposure seems to be greatest, nor was it associated with other problems of growth and development. Children 1 year older or 1 year younger had no such increase. Response or observer bias in these observations does not seem probable.

We do not know of any specific mechanism to explain this observation, nor of comparable reports. We hypothesize that the manifestation of childhood asthma could be associated with an immunological effect of radiation on the developing fetus. Impaired cellular and humoral mechanisms of immunity, as well as autoimmune processes, have been found among children and adults residing in radioactively contaminated areas near Chernobyl (4,10,11) and among liquidators (12,13). Kulakov et al. (14) reported alterations in immunoglobulins and increases in levels of C-reactive protein in serum of pregnant women living in areas contaminated by the Chernobyl fallout.

Exposure to radiation *in utero* can cause childhood leukemia and other tumors (15–17), mental retardation (18), and seizures (19). A detailed review of these effects is presented by Upton et al. (20) and, Nussbaum and Köhnlein (21). Under the auspices of the World Health Organization, Prilipko et al. (22) are following several thousand children exposed to radiation *in utero* to evaluate evidence of

**Table 3.** Health disorders in immigrants, self-reported and physician-diagnosed, 1991–1992<sup>a</sup>

	Frequency of disorders (%)					
	Adults		Adolescents		Children	
	L (N = 55)	R (N = 830)	ME (N = 55)	LE (N = 43)	ME (N = 53)	LE (N = 51)
Respiratory	87.3 <sup>†</sup>	54.5	39.6	39.2	78.8*	60.9
Central nervous	65.4**	52.1	32.6	37.1	51.5 <sup>†</sup>	15.5
Cardiovascular	89.1**	76.1	49.1*	27.5	4.5	1.5
Gastrointestinal	74.5	69.3	37.7	25.5	40.5	30.4
Genitourinary	70.9	62.7	32.1	19.6	36.4	26.1
Musculoskeletal	69.1	62.3	28.3	25.5	37.9	30.4
General symptoms	65.4	61.1	35.9	29.4	36.4	27.5

Abbreviations: L, liquidators; R, total residents; ME, residents of more exposed areas; LE, residents of less exposed areas.

<sup>a</sup>Data are for ages as of 1991. Adults are persons ≥ 19 years old; adolescents are 15–18 years old; and children were born after the explosion on 26 April 1986.

\**p* < 0.05; \*\**p* < 0.01; <sup>†</sup>*p* < 0.001.

mental retardation. This cohort could also provide data on asthma in radiation-exposed children, although bronchial asthma has not yet been noted in this cohort.

### Changes in Blood Pressure

The concordance between history of hypertension and measurements of blood pressure in elderly residents of more exposed areas compared to those from less exposed is evidence against recall or reporting bias. Hypertension has multiple causes, and we considered only whether, among older subjects, a valid association with Chernobyl could be inferred from our observations. Our results concerning arterial blood pressure are in agreement with data from other studies: incidence of hypertension in people living near Chernobyl has increased (23), and a high percentage (27.2%) of borderline arterial hypertension was noted among 107 liquidators, aged to 39 (24). People living near Three Mile Island nuclear power station exhibited higher levels of blood pressure than those from control areas (25); however, it has been asserted that there was almost no radiation exposure at Three Mile Island. Tsyb reported a dose-response relationship between incidence of cardiovascular disease and exposure in liquidators (3). Such effects have been considered a response to a strong psychoemotional tension in liquidators resulting from both their work and radiation phobia (24) and a response to chronic stress in residents (25).

No doubt, stress occurred among our population, but we do not believe that stress is entirely responsible: adults from more exposed and less exposed areas did not know local contamination ratings and therefore could not have been differentially stressed. Furthermore, stress is believed to cause changes primarily in systolic pressure, but we observed differences in both components of arterial blood pressure.

Chernogus and Kupchinskaia (26) examined hypertensive patients from Kiev and from an area within a 30-km radius of the Chernobyl nuclear power plant and compared T-lymphocyte counts and T-suppressors with those from a sample of normal blood donors. Hypertensive patients had reduced levels of T-lymphocytes, T-suppressors, and T-helpers, an effect which was greater in the residents of the more exposed areas. The authors hypothesized that these decreases reflect mechanisms affecting the progression of vascular disease. Tests of blood serum in 340 liquidators revealed increased levels of autoantibodies to neurospecific brain proteins (27). This finding is considered possibly relevant to chronic postradiation encephalopathy, with which hypertension may be associated.

In a series of investigations in liquidators, Voloshin et al. (28) using Doppler sonography and magnetic resonance imaging (MRI), detected increased vascular tension and reduced cerebral vessel blood flow. Using MRI, they also noted structural changes in the brain.

Kundiev et al. (29) found lead pollution near the damaged reactor and symptoms consistent with lead exposure, suggesting that the observed hypertension may be lead related. Kodama (30), reviewing the data on cardiovascular disease following the atomic bomb explosions in Hiroshima and Nagasaki, failed to find evidence of an effect on blood pressure in the majority of studies (29).

### Thyroid Changes Associated with Former Residence

We found no increase in the prevalence of enlargement of the thyroid gland (goiter) in more exposed compared to less exposed communities. The exposure estimate was based on the ground level and body burden of  $^{137}\text{Cs}$ , whereas any thyroid effects are more likely to be related to exposure to isotopes of iodine, which would have occurred in the early post-explosion period. We have no reason to believe that  $^{137}\text{Cs}$  is related to thyroid nodularity. However, Likhtarev et al. (31), in deriving thyroid dose assessment in the Ukraine, used  $^{137}\text{Cs}$  deposition, among other variables, and were able to show a good relationship between derived doses and thyroid cancer.

Our results of blood tests show no deviations from expected levels of antithyroid autoimmune processes or other thyroid function tests in children, which might be related to exposures to  $^{131}\text{I}$  (Wynberg et al., unpublished data). We found no differences that could be related to  $^{137}\text{Cs}$  exposure. We also could not define gradients for  $^{131}\text{I}$ .

The data on occurrence of thyroid cancer in radiation-exposed children (32) lend importance to the increase in nodularity observed in children from the more exposed communities, even though the results are not significant. Three thyroid cancers, two in adolescents, have been observed in our population.

### Other Chronic Conditions

The excess of chronic health disorders (self-reported and physician-diagnosed) in liquidators compared to residents and in residents from more exposed communities compared to those from less exposed is not explicable as a mere consequence of stress.

Kulakov et al. (14), after studying 688 pregnant women and their babies and 7000 delivery records during the 3 years before the Chernobyl accident and 5 years

afterward, concluded that health of mothers, fetuses, and children in contaminated areas were significantly affected by radiation. In a district where 53% of women lived with ground level pollution greater than  $20 \text{ kCi/km}^2$ , there was an increase in perinatal mortality for the 3 years after the accident from 15.1% to 17.8%, whereas in another district with only 20% of the women exposed to this level of contamination, the perinatal mortality rate dropped from 11.5% to 7.3%. Guskova (33) considers that increasing rates of cardiovascular pathology, endocrine dysfunctions, and worsening of respiratory and digestive system diseases among residents of exposed regions are the result of the chronic stress.

Nussbaum and Kohnlein (21) point out some inconsistencies and unresolved questions concerning low-dose health effects of ionizing radiation. They deplore the use of A-bomb survivor studies as a "universal standard." They note that the hypothesis of reduced biological effectiveness of fractionated low-dose exposure compared to that of the same acute dose is not supported by data on human populations. They call attention to observations of other diseases than radiation-induced malignancy, suspected to be associated with relatively low levels of internal exposure. Our observations also indicate that effects other than cancer should be investigated.

### Conclusions

It may be reasonably assumed that the health effects we observed are associated with exposure to radiation from the Chernobyl disaster. However, only some of the effect may be due to radiation itself. The occurrence of stress disorders in persons exposed to radiation from the Chernobyl accident is not a valid argument against the etiological role of radiation alone or in combination with other pollutants. The exposures of relevance could be brief or long term; for example, food contamination by  $^{137}\text{Cs}$ .

As a result of our findings, we are convinced that a preoccupation with carcinogenesis as the principal consequence of Chernobyl exposures has led to a distorted view of health effects of low-level radiation. While such attention has stimulated studies of possible mutagenic mechanisms, mutagenesis may also result in non-neoplastic abnormalities. Elsewhere we report our study of oxygen free radical mechanisms and possible consequences (34).

We believe that our data point to opportunities to both relieve the anxieties and improve the health of those who were exposed, as well as contribute to the knowledge of low-level radiation effects.

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